Extracted from Annex A of the WMO SAT-26, Tech. Document 1052: STATEMENT OF GUIDANCE REGARDING HOW WELL SATELLITE AND IN-SITU SENSOR CAPABILITIES MEET WMO USER REQUIREMENTS IN SEVERAL APPLICATION AREAS.

SUMMARY OF SATELLITE OBSERVING SYSTEM CAPABILITIES

A.1 Satellite System Capabilities

The current operational meteorological satellite observing system comprises a constellation of geostationary and polar orbiting satellites operated by various space agencies. Each satellite has a payload of instruments including as a minimum a multispectral imaging radiometer. The satellite systems capabilities database has been drafted with input from each of the operational satellite operators. This will continue to be an evolving data set and will be updated every year.

A.1.1 Polar platforms

Polar orbiters allow a global coverage to be obtained from each satellite but only twice a day. To provide a reasonable temporal sampling for many applications at least two satellites are required, thereby providing 6-hourly coverage. A backup capability exists by reactivating 'retired' platforms and this has been demonstrated recently. Since 1979, coverage with two polar orbiting satellites has been achieved most of the time. The orbital altitude of 850 km makes it technically feasible to make high spatial resolution measurements of the atmosphere/surface.

Current operational polar orbiters include the NOAA series from the USA and the METEOR, RESURS, and OKEAN series from Russia and the FY-1 series from China. They provide image data that can be received locally. The NOAA satellites also enable generation of atmospheric sounding products that are disseminated to NWP centres on the GTS. In the future, the NOAA AM satellite will be replaced by the METOP satellites provided by EUMETSAT.

The primary imaging and sounding instruments that have been or will soon be a part of the polar orbiting series of operational satellites include:

Visible and Infrared Radiometers

The Advanced Very High Resolution Radiometer (AVHRR), flown in October 1978 on TIROS N, measures radiation in five visible and IR windows at 1 km resolution. This will transition to a more capable visible and infrared imager called the Visible Infrared Imaging Radiometer Suite (VIIRS), when the NOAA satellites become the NPOESS series, starting with a demonstration programme in 2005, called the NPOESS Preparatory Project (NPP). VIIRS will be better calibrated than the AVHRR, have higher spatial resolution (400 metres vs. 1 km at nadir), and have additional spectral capability including channels that can be utilized to determine ocean colour. Parameters that may be derived from the VIIRS for use in operational as well as climate monitoring include sea surface temperature, aerosols, snow cover, cloud cover, surface albedo, vegetation index, sea ice, and ocean colour.

Atmospheric Temperature and Humidity Sounders

The TIROS Operational Vertical Sounder (TOVS) has evolved to an advanced version in 1998 and consists of the High resolution Infrared Radiation Sounder (HIRS) and the Advanced Microwave Sounding Unit (AMSU). These IR and microwave sounders produce soundings in clear and cloudy (non-precipitating) skies every 50 km. Atmospheric temperature and moisture information is derived indirectly through channel measurements that are sensitive to emissions by carbon dioxide and water vapour. Enough information is collected to infer temperature and moisture concentration within several thick layers in the vertical. Most forecast centres now prefer to deal with the more basic information from the channels themselves rather than retrieval. The efficacy of satellite information in numerical prediction depends partly upon the physical nature of the measurements and partly upon the sophistication of the data assimilation procedures, which are constantly being improved. Polar orbiting satellites provide information on temperature with global coverage, acceptable accuracy, good horizontal resolution, but marginal temporal frequency and vertical resolution for the purpose of mesoscale prediction. The use of radiances over land is still experimental, though recent improvements in assimilating oceanic data have led to better global forecasts. Polar orbiting satellites have microwave sounders that can penetrate clouds (the Advanced Microwave Sounding Unit-AMSU), but the field of view of this instrument is broader than that for infrared sounders. As with infrared soundings, progress is slow in utilizing them over land. NOAA will be transitioning to more capable sounders in the NPOESS series, starting with the NPP demonstration program in 2005. HIRS will be replaced by the Cross track Infrared Sounder (CRIS), a Michelson interferometer that is designed to enable retrievals of atmospheric temperature profiles at 1 degree accuracy for 1 km layers in the troposphere, and moisture profiles accurate to 15 percent for 2 km layers. This is accomplished by the CrIS working together with the Advanced Technology Microwave Sounder (ATMS), being designed to be the next generation cross track microwave sounder (CrMS). Comparable sounding capability will be realized on the METOP series by the Infrared Atmospheric Sounding Interferometer (IASI) in conjunction with the advanced microwave temperature sounding units (AMSU-A) and microwave humidity sounders (MHS / HSB). CrIS/ATMS will fly in afternoon (1330 ascending) and IASI/AMSU/MHS will fly in morning (0930 descending) orbit.

A complementary series of DMSP satellites in polar orbit fly a scanning microwave radiometer called the Special Sensor Microwave Imager (SSM/I), flown since June 1987. A conical scanning version of the microwave sounder will be flown on NPOESS. The Conical Microwave Imager Sounder (CMIS) data can be utilized to derive a variety of parameters for operations and research including all weather sea surface temperature, surface wetness, precipitation, cloud liquid water, cloud base height, snow water equivalent, surface winds, atmospheric vertical moisture profile, and atmospheric vertical temperature profile.

Scatterometers

Polar orbiting satellites provide information on sea-surface winds in two ways: Scatterometers provide dense observations of wind direction and speed along a narrow swath. Passive microwave imagers provide information on wind speed only. Radar scatterometers have been shown to have a significant positive impact in predicting marine forecasting, operational global numerical weather prediction, and climate forecasting. Quickscat, launched in 1999 on a research platform, carries Seawinds and another is scheduled to fly on ADEOS-2 in 2000. No additional U.S. scatterometer missions are planned before the operational NPOESS, which plans to use a passive microwave approach to determining the ocean vector wind field. This passive microwave technique will be tested as part of the Windsat Coriolis mission scheduled for late 2001. Europe's METOP series of satellites, scheduled to begin flying in 2003 include an Advanced Scatterometer (ASCAT) sensor, but ASCAT alone may not be able to provide the required geographic coverage and frequency of observations needed for operations and research. Japan has offered to fly a scatterometer on ADEOS-3, but a decision is still pending.

A.1.2 Geostationary platforms

The geosynchronous orbit is over 40 times higher than a polar orbit, which makes measurements technically more difficult from geostationary platforms. The advantage of the geostationary orbit is that it allows frequent measurements over the same region necessary for nowcasting applications and synoptic meteorology. A disadvantage is that a fixed full disk view of the Earth is viewed from one satellite. Thus, five equally spaced satellites around the equator are needed to provide global coverage; polar regions are reviewed poorly at large zenith angles.

Currently, there is global coverage from geostationary orbit (>5 operational satellites) for image data and products (e.g., cloud motion winds) and 2 satellites are providing a sounding capability as well. Backup is provided by reactivating 'retired' platforms and there have been several examples of this. The present geostationary satellite locations include: at 0° longitude and 63°E (operated by the EUMETSAT); a satellite at 76°E (operated by the Russian Federation); a satellite at 105°E (operated by the People's Republic of China); a satellite at 140°E (operated by Japan); and, satellites at 135°W and 75°W (operated by the USA).

Some of these satellites provide a real-time reception capability to allow immediate access to the imagery for real-time applications. Products are disseminated on the GTS by the satellite operators for near real-time applications.

The primary imaging and sounding instruments that have been or will soon be a part of the geostationary series of operational satellites include:

Visible and Infrared Radiometers

The Visible and Infrared Spin Scan Radiometer (VISSR), flown since 1974, has been the mainstay of geostationary imaging on GOES, Meteosat, and GMS. Changes are underway. Europe is moving to SEVIRI with 12 channels of visible and infrared measurements at 3 km resolution full disk every 15 minutes. Japan will embark on the MTSAT-1R with 5 channels of visible and infrared measurements at 5 km resolution full disk every 30 minutes. China has the FY-2 series of imagers that will be adding several spectral channels to their current visible and infrared window measurements. The USA will evolve from their current Imager with 5 channels of visible and infrared measurements at 5 km resolution full disk every 30 minutes to an Advanced Baseline Imager (ABI) that makes full disk images in 8 to 12 spectral bands in 5 minutes at 2 km infrared and 0.5 km visible resolution. ABI offers improved performance over current GOES in all dimensions (routine full Earth disk imaging while enabling mesoscale sub one minute interval imaging, better navigation, more noise free signals, and additional spectral bands for improved moisture feature detection).

Geosynchronous radiometers are used to track clouds both in visible and infrared images at multiple levels. Features are also tracked in channels that are sensitive to moisture (the so-called *water vapour* channels). Geosynchronous satellites, which provide frequent views of the same target, are required for tracking. These satellites orbit above the equator; they do not observe the polar regions well enough to track features there. Moreover, if a cloud fills a field of view in the infrared image, its height can be estimated from knowledge of the cloud top temperature. If the field of view is only partially filled or if the target cloud is semi-transparent, there is more uncertainty in estimating the cloud height because part or all of the field of view may be receiving radiation from the ground. In the case of features in a water vapour channel, many of these are not clouds, and the swirls and shapes that move in the images are the result of radiation coming from a layer that is normally kilometres deep. Height assignment is this case is ambiguous because what is sensed is really a layer-averaged motion. Cloud-track winds are most accurate when the cloud targets are fairly small (but not too small), not associated with standing waves, and non-convective. Clear-air wind determination by satellite depends upon radiometric data, and radiation in each channel comes from deep layers in the atmosphere, thereby precluding high vertical resolution. Satellite wind information is particularly useful where other sources of wind information are lacking.

Infrared Sounders

With the three axis stable platform on GOES-8, NOAA was able to introduce geostationary infrared sounders. Measuring the infrared radiation in 18 spectral bands, these sounders provide temperature and moisture sounding over North America and nearby oceans every hour every 30 km (in clear skies). Geosynchronous satellites provide frequent radiance data, but their use over land is still hindered because of the difficulty of estimating surface emissivity. Infrared soundings cannot be made below clouds because all but very thin clouds are opaque to infrared radiation. NOAA plans to evolve to the Advanced Baseline Sounder (ABS) in 2009, using an interferometer, focal plane detector arrays, and on board data processing to cover 3.7 to 15.4 microns with 2000 plus channels measuring radiation from 10 km resolution; contiguous coverage of 6000 by 5000 km will be accomplished in less than 60 minutes. NASA will be demonstrating the technology necessary for ABS, with the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) in 2004. GIFTS will improve observation of all three basic atmospheric state variables (temperature, moisture, and wind velocity) with much higher spatial, vertical, and temporal resolutions. Water vapour, cloud, and trace gas features will be used as tracers of atmospheric transport.

A.1.3 Research and applications satellites

Research systems are valuable for demonstrating new instruments for possible future operational systems. To date, research satellites have been flown by several agencies of which TRMM, and ADEOS are examples. The recently launched EOS and soon to be launched ENVISAT platforms are another. Applications satellites with a limited number of missions, such as ERS, also provide important contributions. More recently, measurements based in radio occultation technology such as the GPS/GLONASS have been added to the database of satellite capabilities. However, a long-term commitment to providing research and applications data routinely is necessary to increase the utility of all these data.

A.2.8 GPS (Ground- and Satellite-based)

The delay in the Global Positioning System (GPS) signal due to atmospheric water vapour can be converted to equivalent water vapour content. Ground based GPS offers an all-weather system that can provide continuous measurements with little or no need for calibration checks. Accuracies of 1 mm can be obtained if collocated surface pressure and temperature are available. Satellite based GPS uses occultation between the constellation of GPS satellite transmitters and receivers on LEO satellites. Ray bending and changes in the phase and amplitude of the transmitted signals allowing inference of the upper atmosphere temperature profile to the order of 1 deg K or better between altitudes of 8 to 30 km in layers (it is unclear what the phrase inside the “<>” means) < of some 1 km x 30 km extent> with near global coverage. The coverage would be expected to be evenly spread over the globe, excepting polar regions. COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) plans to launch eight LEO satellites in 2002, each COSMIC satellite will retrieve about 500 daily profiles of key ionospheric and atmospheric properties from the tracked GPS radio-signals as they are occulted behind the Earth limb. The constellation will provide frequent global snapshots of the atmosphere and ionosphere with about 4000 daily soundings.

GPS technology is advancing very rapidly, and ground-based receivers are numerous in populated areas, though it is likely that only a small percentage of these are collocated with surface observing sites. Japan has a dense network of GPS sites used for estimating total column water vapour; the U.S. network should grow to 200 sites within three years. The possibility that 3-D moisture information might be extracted from dense GPS networks through analysis of signal delay along slant paths is under investigation.